SUGARCANE

Periodic Flooding and Water Table Effects on Two Sugarcane Genotypes

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ABSTRACT

Sugarcane (*Saccharum* spp.) in Florida is increasingly exposed to periodic floods and high water tables for extended durations. We evaluated the effects of periodic flooding, followed by drainage, on morphological characteristics and cane and sugar yields of two sugarcane genotypes. From 2000–2002, experiments were conducted in lysimeters filled with Pahokee muck soil. Flooding was imposed for 7 d during five, nine, and nine 21-d cycles in 2000, 2001, and 2002, respectively. Cycles commenced when sugarcane leaves covered the rows and were discontinued in mid-October. Water table depths during the 14-d drainage period of each cycle were 16, 33, or 50 cm. A fourth treatment was maintained continuously at a 50-cm water table depth. Genotype CP 95-1429 yields were not affected by water table or flooding. For CP 95-1376 in periodic-flooding treatments, lowering the water table in 1-cm increments increased cane and sugar yields by 0.16 and 0.02 kg m^{-2}, respectively, in 2000 and 0.25 and 0.03 kg m^{-2}, respectively, in 2001. Water table depth during drainage did not affect CP 95-1376 yields in 2002, perhaps because of a longer duration between planting and initial flooding in 2002. Each day of flooding reduced cane and sugar yields of CP 95-1376 by 0.17 and 0.02 kg m^{-2}, respectively, in 2000 and by 0.21 and 0.03 kg m^{-2}, respectively, in 2002. Flooding might not have reduced yields of CP 95-1429 because of its ability to form aerenchyma in the stalks before exposure to flooding. Such genotypes should be able to tolerate flooding for at least 1 wk.

THE EVERGLADES AGRICULTURAL AREA (EAA) is a 280 000-ha basin of Histosols that lies on limestone bedrock in the northern region of the historic Everglades in Florida. Sugarcane is grown on about 148 000 ha in the EAA (Glaz, 2002). Before construction of an extensive public/private system of canals through the northern Everglades, the EAA was flooded most of the time (Snyder and Davidson, 1994). Until recently, farmers used the canal system to effectively manage desired water table depths of 40 to 95 cm in sugarcane fields (Omary and Izuno, 1995).

Several factors have resulted in increased exposure of EAA sugarcane to extended periods of higher-than-desired water tables and to floods for as long as 7 d. Soil subsidence caused loss of depth in EAA Histosols at the rate of about 2.5 cm yr^{-1} before 1978 (Shih et al., 1978). From 1978 until the most recent survey in 1997, the rate of soil loss declined to 1.4 cm yr^{-1} (Shih

et al., 1998). Some EAA fields had as much as 300 cm of soil above the limestone bedrock when they were first drained and used for agriculture. Depth of soil to bedrock varies, but a small number of sugarcane fields now have less than 40 cm of soil (Shih et al., 1998). Second, for every centimeter of rainfall, the water in the soil profile of EAA Histosols rises about 10 cm (Glaz et al., 2002). Finally, there are regulated and voluntary limits on pumping from farm ditches to public canals as a means of reducing P discharge to the natural Everglades.

The issues of soil subsidence and P discharge also provide incentives to maintain yields under high water tables and periodic flooding. The primary cause of subsidence in the EAA is microbial oxidation (Tate, 1980). The factor that most influences the rate of microbial oxidation is depth of water table in the soil profile. Therefore, the rates of oxidation and subsidence are directly proportional to the depth of the water table. Halving the distance between the water table and the soil surface has been shown to halve the rate of subsidence (Snyder et al., 1978).

Best management practices to reduce P discharge from the EAA often include strategies to reduce quantities and rates of pumping water from agricultural fields (Rice et al., 2002). Therefore, P export to the Everglades could be reduced by allowing high water tables and floods in sugarcane to descend more by evapotranspiration and less by pumping. Developing strategies that allow water tables closer to the soil surface along with increased flood durations at which sugarcane maintains optimum yields would help conserve soil and reduce P discharge.

Previous research indicates inconsistent sugarcane responses to water tables. Carter and Floyd (1971) reported that maintaining four constant water tables between depths of 61 and 122 cm during the active growth phase of sugarcane did not affect cane or sugar yields in Louisiana. Carter and Floyd (1975) maintained water tables at 30, 76, and 122 cm throughout the year in the second- and third-ratoon crops of the plantings reported in their 1971 study. There were no significant differences in sugar yield in the second-ratoon crop, but in the third-ratoon crop, sugar yields decreased as water table rose.

In a field study conducted in Florida, Kang et al. (1986) compared sugar concentration and cane yields of 16 clones of sugarcane (*Saccharum* spp.), one of *S. robustum*, one of *S. officinarum*, and one of *Ripidium* spp., at water table depths of 30 and 56 cm. Overall

Abbreviations: EAA, Everglades Agricultural Area; TRS, theoretical recoverable sugar.

mean sugar concentration yields were 15.7 and 17.6% higher in the 30-cm water table depth in the plant-cane and first-ratoon crops, respectively. Overall mean cane yields were 27.5 and 25.3% higher in the 30-cm water table depth in the plant-cane and first-ratoon crops, respectively. Gascho and Shih (1979) maintained water table depths in lysimeters at 32, 61, and 84 cm. They reported that yields were optimum at 61 cm, but two of six cultivars had similar yields at all three water tables. Glaz et al. (2002) maintained, in the field, summer water table depths of <15 cm and between 15 and 38 cm for plant-cane and first-ratoon crops. Sugar yields at the water table maintained at <15 cm from the soil surface were 91.7% of those at the deeper water table. However, yield of one cultivar was reduced by 25% by the shallow water table, and yields of two of nine cultivars were not affected by water table.

Mafizur Rahman et al. (1986) reported that flooding in pots for one month in Louisiana reduced stalk growth rates among genotypes by 40 to 88%. In Barbados, Webster and Eavis (1972) flooded sugarcane in lysimeters for 1, 4, 14, or 30 d at 1- and 3-mo age. During the flooding, tiller formation and shoot growth were decreased, but increased growth after drainage relative to the nonflooded lysimeters resulted in similar yields for all treatments at 5-mo age. Although root weight was similar for all treatments at 5 mo, the flooded sugarcane had fewer and larger roots than the drained sugarcane. In a study conducted outdoors in large pots, Ray and Sinclair (personal communication, 2003) observed that continuous flooding reduced sugarcane yields and that a continuous water table depth of 15 cm resulted in neutral or beneficial yield responses for all three cultivars tested. Deren et al. (1991b) reported that 5-mo flooding reduced yields of 160 sugarcane genotypes by 30 to 100%.

In summary, previous research shows that sugarcane suffers moderate to total yield losses due to long-duration flooding. Optimum yields have sometimes been identified at water table depths of ≤30 cm, but optimum yields have generally been reported at water tables substantially deeper than 30 cm. Also, clear reasons to explain the response of sugarcane to different water table depths have not been reported. For EAA sugarcane growers, water table management is more complex than managing only for extended flood or only for high water table duration. Instead, sugarcane is exposed to periodic floods, usually not for durations longer than 1 wk, and when drained, it is often difficult to drain to the desired depth of about 50 cm. The purpose of this study was to evaluate the effects of periodic flooding, followed by drainage to different water table depths, on morphological characteristics and cane and sugar yields of two sugarcane genotypes.

MATERIALS AND METHODS

Twelve polyethylene containers equipped as lysimeters were placed into the ground and filled with Pahokee muck soil (euic, hyperthermic Lithic Haplosaprist). Lysimeters were 1.5 m wide by 2.6 m long by 0.6 m deep and placed where there was no shade. Soil was collected in three arbitrary horizons of 20 cm each from an EAA field that had never been cropped. Soil collected from the deepest 20-cm horizon was placed in the lysimeters, flooded, and then drained, followed by soil from the next deepest 20-cm layer. The process was continued until the lysimeters were filled. For about 3 mo before planting, the soil in the lysimeters was exposed to cycles of 2-wk flooding followed by drainage for 3 d. Soil bulk densities were not determined at the beginning of this study, but at the conclusion, bulk densities at the 15- and 30-cm depths were 0.29 and 0.21 g cm^{-3}, respectively, which were within the range of bulk densities expected of EAA Histosols (Lucas, 1982).

A pump connected to a ball float was installed in each lysimeter to remove excess water. About 40 L of well water flowed into each lysimeter daily from a hose placed inside a perforated pipe that extended from one corner of the lysimeter above the soil surface to the diagonal corner at the bottom of the lysimeter. A solenoid valve installed on each lysimeter opened automatically each morning for 2 min to permit this water flow. This volume of water was sufficient to return lysimeters to desired water tables each morning if water was lost the previous day. Water levels in each lysimeter were measured before the scheduled opening of the solenoid valve manually 5 d wk^{-1} in 2000 and daily by automatic recorders in 2001 and 2002 (Table 1). Soil samples were taken from the 0- to 15-cm depth and analyzed for pH (water) and water extractable P and K (Sanchez, 1990). Based on soil test recommendations (Sanchez, 1990), nutrients were banded near the planted sugarcane each year at rates of 25 and 139 kg ha^{-1} of P and K, respectively, and at rates of 0.1, 0.1, 0.7, 0.3, 0.1, and 0.3 kg ha^{-1} of B, Cu, Fe, Mn, Mo, and Zn, respectively.

On 15 May 2000, each lysimeter was drained, and sugarcane was planted in 2.6-m-long rows that were spaced 1.2 m apart. One row in each lysimeter was randomly planted with genotype CP 95-1376 and the other row with genotype CP 95-1429. On the basis of their high yields and similarity to commercial sugarcane cultivars in Florida, both of these noncommercial genotypes were previously advanced to the final selection stage of the cooperative breeding program at a USDA facility, located at Canal Point, FL.

Each year, all lysimeters were maintained at water table depths of 50 cm from after planting until treatments were applied. Four water table treatments, each replicated three times, were first imposed on 4 July 2000. One treatment that served as a control was a water table depth continuously maintained at 50 cm. The three other water table treatments included flooding for the first 7 d of five 21-d cycles and drainage to depths of 16, 33, and 50 cm for the remaining 14 d of each cycle in the experiment conducted in 2000. During flood, water height ranged from at the soil surface to about 2.5 cm above the soil surface. Flooding durations of 7 d were chosen because this duration approximates the longest duration to which commercial sugarcane in the EAA is sometimes exposed. The 50-cm drainage depth was chosen because it is a desired commercial depth, and two incrementally higher depths were cho-

Table 1. Target and measured water table depths for 2000–2002.

Target water table†	2000	2001	2002	Mean
		cm		
50 cm always	47.9	47.5	44.7	46.7
16 cm and flood	17.2	17.9	20.1	18.4
33 cm and flood	33.2	33.2	33.7	33.4
50 cm and flood	48.4	48.4	45.3	47.4

† Target water table depths were continuously 50 cm and 16, 33, and 50 cm for 2 wk followed by 1 wk of flooding for five, nine, and nine cycles in 2000, 2001, and 2002, respectively. After these cycles, target water table depths were 16, 33, and 50 cm.

sen because such depths are becoming increasingly common for extended durations in commercial fields.

In the second experiment, planted on 1 Feb. 2001, the water treatments began on 17 Apr. 2001 and continued for nine flood–drain cycles. A third experiment was planted on 23 Jan. 2002, and a total of nine flood–drain cycles began on 6 May 2002. Flood–drain cycles in all experiments began when the interrow space was covered by the plant leaves and were discontinued in the final half of October to coincide with the dry season in Florida. After the final flood–drain cycle of each experiment, water tables were maintained at their prescribed drainage depths until harvest.

Each year, all sugarcane stalks were cut at their base from each row of each lysimeter. Immature stalks (suckers) were discarded. After removal of their top four internodes, all remaining stalks were weighed to determine cane yield measured as kilograms per square meter. Except for five stalks, all stalks were then milled to extract juice and determine theoretical recoverable sugar (TRS, measured as g sugar kg^{-1} cane), calculated using a previously described procedure (Legendre, 1992). Sugar yield (kg sugar m^{-2}) was calculated as follows:

$$\text{Sugar yield} = (\text{TRS} \times \text{cane yield})/1000$$

Harvest dates were 19 Jan. 2001, 14 Nov. 2001, and 10 Dec. 2002 for the first, second, and third experiments, respectively.

Soon after the harvest of the second experiment, while digging out the sugarcane stools, white grub (*Ligyrus subtropicus* Blatchley) infestations were detected in the three lysimeters that were maintained at a continuous 50-cm water table depth (not flooded). The nine lysimeters that were cyclically flooded for 7-d did not have white grubs, as expected (Cherry, 1984). Based on their life cycle, the white grubs probably began causing damage in August or September in the lysimeters that were not flooded (Cherry, 1991). In the final experiment, all lysimeters were flooded from 25 Sept. 2002 to 3 Oct. 2002 as a control measure. No white grubs were found in any lysimeters when digging up sugarcane stools after the first and third experiments.

Morphological characters were measured on the five stalks not used to measure TRS. Nodes from the bottom of the cut stalk were counted, and diameter was measured on the second internode from the bottom of each stalk. Also on the internal portion of the second internode from the bottom of the cut stalk, a subjective rating was assigned for relative size of pith and pipe (air cavity) combined. (Any pipe was always within the pithy portion of the stalk.) We are not aware that the pipes within this area of pith have been described as aerenchyma in sugarcane, but these pipes are probably similar to what has been characterized in stems of other species as aerenchyma. Aerenchyma formation in stems and roots is due to cell separation during development (schizogeny) or cell death and dissolution (lysigeny) (Drew, 1997). Aerenchyma formation has

been reported to be routine in sugarcane roots (Ray et al., 1996; Van Der Heyden et al., 1998). The ratings of pithy area with aerenchyma formation ranged from 0 for none to 5 for an area that was equal to about 70% of the stalk diameter. Leaves were collected and separated into brown and green leaves. Brown leaves, green leaves, and stalks were oven-dried, and dry weights were recorded for each.

Water table treatments (lysimeters) were arranged as main plots in a randomized complete block design. All water table treatments were replicated three times. Genotypes were arranged as split plots in lysimeters. All statistical analyses were performed using PROC MIXED of SAS (SAS Inst., 1999). Data were analyzed for each year separately. Analyses of morphological characters included five samples of each experimental unit. Analyses were also conducted with the combined data of all three experiments (years) for all characters. In analyses of separate years, or analyses combined across years, replication and sample or year (when present), and any interaction including these terms, were classified as random effects. The water table and genotype treatments were treated as fixed effects.

Significant effects identified by analysis of variance were further analyzed by separating least square means with *t* tests. Also, the contrast statement in SAS (SAS Inst., 1999) was used to calculate single degree-of-freedom comparisons that tested significance, for each genotype, of linear regression on water table depth during drainage for treatments that were periodically flooded and drained to 16, 33, and 50 cm. Regressions were calculated using recorded water table depths that differed moderately each year (Table 1). To simplify presentation, graphs and other results are reported as responding to depths of 16, 33, and 50 cm. Differences were identified as significant at $P = 0.05$ and as highly significant at $P = 0.01$.

RESULTS AND DISCUSSION

Yields, Year 2000

There were no significant differences in TRS due to water table, genotype, or the genotype × water table interaction (Tables 2 and 3). Averaged across water tables, genotype CP 95-1376 yielded substantially greater quantities of cane and sugar than CP 95-1429 (Tables 4 and 5). However, the periodic flooding and water table depths during drain periods affected each genotype differently. The cane and sugar yields of CP 95-1376 were significantly higher when exposed to the continuously drained treatment compared with each treatment that was periodically flooded. For the periodically flooded CP 95-1376, incrementally lowering the water table depth during drainage by 1 cm increased cane and sugar yields by 0.16 and 0.02 kg m^{-2}, respectively (Fig. 1).

Table 2. Probabilities of *F* values of fixed effects for yields of theoretical recoverable sugar (TRS), cane, and sugar for two sugarcane genotypes exposed to four water table treatments during 2000–2002.

Fixed effect	2000			2001			200		
	TRS	Cane	Sugar	TRS	Cane	Sugar	TRS	Cane	Sugar
					$P > F$				
Water table (W)	0.35	0.01	0.02	0.22	0.02	0.06	0.91	0.01	0.01
W linear	0.12	0.05	0.04	0.84	0.01	0.02	0.53	0.65	0.73
W quadratic	0.50	0.46	0.30	0.75	0.10	0.17	0.75	0.29	0.25
Genotype (G)	0.07	<0.01	<0.01	0.01	0.05	0.02	0.01	<0.01	<0.01
W × G	0.21	<0.01	0.01	0.48	0.39	0.70	0.97	<0.01	<0.01
CP 95-1376 linear†	0.61	<0.01	<0.01	0.47	<0.01	<0.01	0.82	0.91	0.93
CP 95-1429 linear†	0.13	0.94	0.57	0.73	0.09	0.19	0.55	0.57	0.39

† Linear response to water table depth after drainage was calculated for each genotype separately.

Table 3. Effects of four water table treatments and two sugarcane genotypes on yields of theoretical recoverable sugar during 2000–2002.

Treatment†	2000	2001	2002	Mean
		g kg^{-1}		
50 always	124.87 A‡	129.43 A	124.77 A	126.36 A
16 and flood	119.97 A	124.14 A	125.64 A	123.18 A
33 and flood	121.25 A	122.86 A	125.43 A	123.44 A
50 and flood	127.82 A	123.44 A	124.12 A	125.05 A
CP 95-1376	126.19	128.69	127.43	127.53
CP 95-1429	120.76	121.24	122.55	121.43
$P > t$	0.07	0.01	0.01	<0.01
Overall mean	123.67	124.97	124.88	124.51

† Target treatments were water table depths of 50 cm always and cycles of flooding for 1 wk followed by depths of 16, 33, and 50 cm for 2 wk for five, nine, and nine cycles in 2000, 2001, and 2002, respectively. After these cycles, target water table depths were 16, 33, and 50 cm.

‡ Least square means of water table treatments in the same column followed by the same letter are not significantly different at P = 0.05 based on t tests.

The cane and sugar yields of the periodically flooded treatments of CP 95-1429 did not differ significantly from the continuously drained CP 95-1429, and they were not affected by water table depth during drainage (Tables 2, 4, and 5).

Yields, Year 2001

The two genotypes differed significantly in yields of TRS, cane, and sugar, with CP 95-1376 having the higher yields (Tables 2, 3, 4, and 5). Differences in cane and sugar yields between the two genotypes were not as substantial as in 2000. Perhaps the cause of the lower CP 95-1429 cane and sugar yields in 2000 was that it did not respond well to the late planting date of that experiment. The commercial sugarcane planting season in Florida extends from August through February, and the experiment in 2000 was not planted until 15 May 2000. Yields of TRS were not affected by water table treatment (Table 2).

The linear responses combined across genotypes of cane and sugar yields to water table depth were signifi-

Table 4. Cane yields of two sugarcane genotypes exposed to four water table treatments during 2000–2002.

Treatment†	Genotype	2000	2001	2002	Mean
			kg m^{-2}		
50 always	CP 95-1376	28.09 A‡	24.75 BC	35.07 A	29.30 A
50 always	CP 95-1429	8.13 D	21.67 C	18.27 B	16.02 C
16 and flood	CP 95-1376	16.94 C	20.89 C	21.59 B	19.85 C
16 and flood	CP 95-1429	8.93 D	20.98 C	18.32 B	16.12 C
33 and flood	CP 95-1376	20.14 BC	26.95 AB	22.31 B	23.42 B
33 and flood	CP 95-1429	10.14 D	25.81 AB	22.23 B	19.39 C
50 and flood	CP 95-1376	22.25 B	29.26 A	21.87 B	24.51 B
50 and flood	CP 95-1429	9.01 D	24.72 AB	19.72 B	17.86 C
50 always	mean	18.11 A	23.21 BC	26.67 A	22.66 A
16 and flood	mean	12.93 C	20.94 C	19.96 B	17.99 B
33 and flood	mean	15.14 BC	26.37 AB	22.67 B	21.41 A
50 and flood	mean	15.63 AB	26.99 A	20.80 B	21.19 A
Mean	CP 95-1376	21.85	25.46	25.21	24.27
Mean	CP 95-1429	9.05	23.30	19.63	17.35
$P > t$		<0.01	0.05	<0.01	<0.01
Overall mean		15.56	24.38	22.49	20.81

† Target treatments were water table depths of 50 cm always and cycles of flooding for 1 wk followed by depths of 16, 33, and 50 cm for 2 wk for five, nine, and nine cycles in 2000, 2001, and 2002, respectively. After these cycles, target water table depths were 16, 33, and 50 cm.

‡ Least square means in the same column and group followed by the same letter are not significantly different at P = 0.05 based on t tests.

Table 5. Sugar yields of two sugarcane genotypes exposed to four water table treatments during 2000–2002.

Treatment†	Genotype	2000	2001	2002	Mean
50 always	CP 95-1376	3.05 A‡	3.28 AB	4.46 A	3.60 A
50 always	CP 95-1429	0.91 D	2.73 BC	2.23 B	1.96 D
16 and flood	CP 95-1376	1.89 C	2.66 BC	2.74 B	2.44 C
16 and flood	CP 95-1429	0.95 D	2.54 C	2.26 B	1.92 D
33 and flood	CP 95-1376	2.42 B	3.49 A	2.86 B	3.00 B
33 and flood	CP 95-1429	1.08 D	3.03 ABC	2.74 B	2.28 CD
50 and flood	CP 95-1376	2.51 B	3.64 A	2.77 B	2.99 B
50 and flood	CP 95-1429	1.05 D	3.02 ABC	2.38 B	2.16 CD
50 always	mean	1.98 A	3.01 AB	3.34 A	2.78 A
16 and flood	mean	1.42 B	2.60 B	2.50 B	2.18 B
33 and flood	mean	1.75 A	3.26 A	2.80 B	2.64 A
50 and flood	mean	1.78 A	3.33 A	2.58 B	2.57 A
Mean	CP 95-1376	2.47	3.27	3.21	3.01
Mean	CP 95-1429	1.00	2.83	2.40	1.96
$P > t$		<0.01	0.02	<0.01	<0.01
Overall mean		1.76	3.05	2.82	2.54

† Target treatments were water table depths of 50 cm always and cycles of flooding for 1 wk followed by depths of 16, 33, and 50 cm for 2 wk for five, nine, and nine cycles in 2000, 2001, and 2002, respectively. After these cycles, target water table depths were 16, 33, and 50 cm.

‡ Least square means in the same column and group followed by the same letter are not significantly different at P = 0.05 based on t tests.

cant (Table 2). However, analysis of each genotype separately revealed that only CP 95-1376 responded linearly to water table depth. For CP 95-1376 flooding treatments, cane and sugar yields increased by 0.25 and 0.03 kg m^{-2}, respectively, for each additional centimeter of water table depth from 16 to 50 cm during drainage (Fig. 1). Cane and sugar yields of each genotype exposed
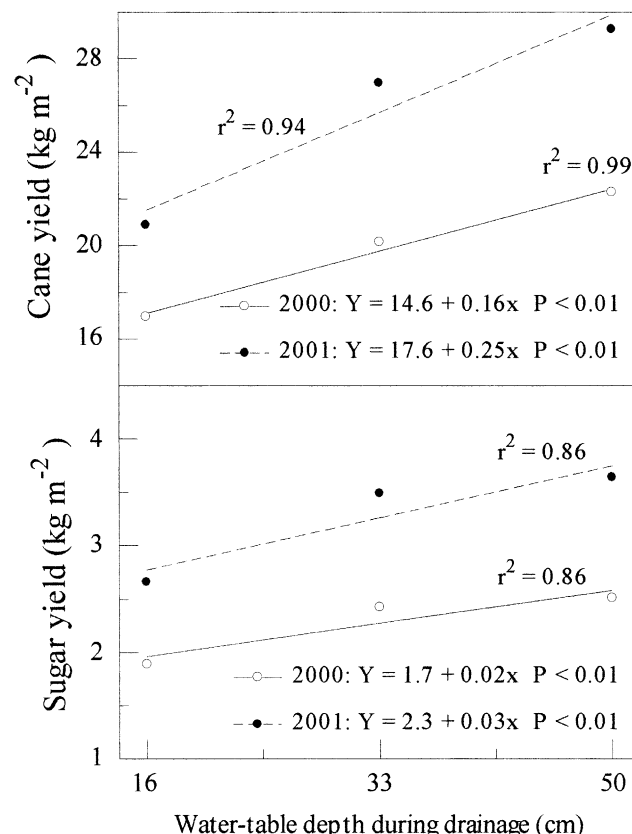

Fig. 1. Cane and sugar yield responses of sugarcane genotype CP 95-1376 to water table depth during 14-d drainage periods that followed cycles of 7-d flooding in 2000 and 2001.

to the continuously drained treatment were not significantly higher than those of any of the periodically flooded treatments (Tables 4 and 5).

Soon after the 2001 harvest, unlike in the previous harvest, white grub infestations of 12.5 grubs m^{-1} row of both genotypes were detected in the continuously drained lysimeters. No grubs were present in any lysimeter treated with a periodic flood. Sosa (1984) reported that white grub infestations of 12.1 m^{-1} row reduced yields of cane and sugar by 28 and 39%, respectively. This grub infestation explains the significantly reduced cane yields of each genotype in the continuously drained treatment compared with its treatment that was exposed to nine cycles of 1-wk flooding followed by water table depths of 50 cm for 2 wk (Table 4). Also, the periodically flooded treatment of CP 95-1429 that was maintained at a water table depth of 33 cm during drainage had significantly higher cane yield than CP 95-1429 maintained at a continuously drained water table. Water table did not affect TRS in years when grubs were and were not present. This suggests that the damage from grubs did not reduce yields of TRS in 2001 (Table 3). Sosa (1984) found significant reductions in sucrose and juice purity due to grub infestations of 12.1 m^{-1} row.

Yields, Year 2002

Similar to results of the previous 2 yr, water table treatment did not affect TRS, and as in 2001, CP 95-1376 had higher yields of TRS, cane, and sugar than CP 95-1429 (Tables 2 and 3). No significant regressions were identified for cane and sugar yield, but water table depth during drainage and water table depth × genotype significantly affected both characters (Table 2). The significant interactions were caused by distinct genotype reactions under periodic flooding compared with continuous drain. Cane and sugar yields of CP 95-1376 were significantly higher in the continuously drained treatment than in all three of the treatments where it was exposed to nine cycles of periodic flooding (Tables 4 and 5). Conversely, CP 95-1429 had similar yields under all four water table treatments. These genotype responses to periodic flooding were similar to their responses in 2000. These responses were not detected in 2001, probably due to the infestation of white grubs.

Unlike in 2000 and 2001, CP 95-1376 yields did not respond linearly to water table depth during drainage. A possible explanation is the amount of time that elapsed between planting and initiation of flood–drain cycles each year. Flood–drain cycles were initiated each year when the sugarcane leaves covered the interrow space in the lysimeters. In 2000 and 2001, flood–drain cycles began 50 and 75 d after planting, respectively. However, in 2002, the experiment was planted earlier, the plants grew more slowly, and the leaves did not cover the rows until 103 d after planting. Perhaps the increased time before exposure to flooding and water table treatments enabled CP 95-1376 to respond more favorably to the 16- and 33-cm water table depths in 2002.

Yield Response to Flooding

Sugarcane in commercial fields in Florida is intermittently exposed to floods, sometimes for durations of approximately 1 wk. The effect of repeated 7-d flooding on yields can be measured by comparing yields (in years 2000 and 2002 when there were no grub infestations) of the treatment continuously drained to 50 cm with those of the treatment flooded and drained to 50 cm for five cycles in 2000 and nine cycles in 2002. Responses to these treatments differed for each genotype. In 2000, cane and sugar yields of CP 95-1376 were 21 and 18% higher, respectively, in the continuously drained treatment compared with the periodically flooded treatment (Tables 4 and 5). In 2002, cane and sugar yields of CP 95-1376 were each 28% higher in the drained treatment compared with the periodically flooded treatment. Yields between flooded and continuously drained CP 95-1429 did not differ significantly in either year.

On the basis of a total of 35 flooded days in 2000, each day of flooding reduced CP 95-1376 cane and sugar yields by 0.17 and 0.02 kg m^{-2}, respectively. In 2002, when total days of flooding numbered 63, each day of flooding reduced cane and sugar yields of CP 95-1376 by 0.21 and 0.03 kg m^{-2}, respectively. Each of these predictions is made from two data points (0 and 35 d in 2000 and 0 and 63 d in 2002). Further research with more than one flood duration may discover that sugarcane yield losses due to flooding are not best explained by linear responses to duration of flood exposure. Periodic flooding did not affect cane and sugar yields of CP 95-1429. Due to restrictions on total daily drainage to public canals, EAA farmers sometimes must choose which of their flooded fields to drain. The losses in yield because of repeated 7-d flooding for one and not the other genotype in this study emphasize the importance of learning the reaction to short-duration floods of existing and future EAA sugarcane cultivars.

Morphological Responses and Implications

Effects of treatments on several morphological characters were also measured. For stalk diameter, number of nodes per stalk, and stalk weight, there were no significant water table effects (data not shown). For green-leaf and brown-leaf weights, no consistent effects of water table were identified (Table 6).

The importance of air cavities, such as aerenchyma for facilitating O_2 transport to flooded roots, has been described previously (Bendix et al., 1994; Grosse and Meyer, 1992; Yoshida and Eguchi, 1994). In species that are flood tolerant, aerenchyma formation is usually constitutive, meaning that it requires no external stimulus, such as flood (Drew, 1997). Deren et al. (1991a) speculated that water table affected air cavity (probably aerenchyma) formation in sugarcane stalks, but their results were not conclusive.

Water table depth during drainage of periodically flooded treatments did not result in significant linear responses of aerenchyma ratings (Table 6). However, averaged across genotypes, the treatment not periodically flooded had a significantly lower aerenchyma rat-

Table 6. Probabilities of F values of fixed effects for dry weights of green and brown leaves and ratings of aerenchyma formation in stalks of two sugarcane genotypes exposed to four water table treatments during 2000–2002.

Fixed effect	Green leaf wt.			Brown leaf wt.			Aerenchyma rating		
	2000	2001	2002	2000	2001	2002	2000	2001	2002
					$P > F$				
Water table (W)	0.15	<0.01	0.60	0.59	0.40	0.43	0.03	<0.01	0.01
W linear	0.04	0.75	0.81	0.45	0.25	0.64	0.83	0.46	0.21
W quadratic	0.55	<0.01	0.64	0.73	0.24	0.14	0.54	0.79	0.96
Genotype (G)	0.15	0.83	0.01	<0.01	<0.01	0.70	<0.01	0.18	0.22
W × G	0.52	0.07	0.84	0.66	0.04	0.09	<0.01	0.13	0.01
CP 95-1376 linear†	0.31	0.56	0.48	0.93	0.75	0.74	0.73	0.87	0.21
CP 95-1429 linear†	0.16	0.56	0.86	0.48	0.04	0.58	0.76	0.39	0.18

† Linear response to water table depth after drainage was calculated for each genotype separately.

ing than all three periodically flooded treatments in all 3 yr (Table 7). Thus, sugarcane responded to periodic flooding by forming more aerenchyma, at least on the bottom of its stalk, the only portion of the stalk we examined. In 2000 and 2001, no aerenchyma formed in the CP 95-1376 that was not exposed to periodic flooding. In 2002, the continuously drained treatments were flooded for 7 d to control grubs. This 7-d flooding explains the aerenchyma formation in CP 95-1376 in 2002. These responses suggest that CP 95-1376 needed exposure to flood to develop aerenchyma whereas CP 95-1429 developed constitutive aerenchyma.

In 2000, aerenchyma ratings in CP 95-1429 were higher in its periodically flooded treatments compared with its continuously drained treatment (Table 7). In 2001 and 2002, both CP 95-1376 and CP 95-1429 had higher aerenchyma ratings in the periodically flooded treatments compared with the continuously drained treatment. The increased aerenchyma formation in periodically flooded CP 95-1376 in 2001 and 2002 was probably caused by the increased number of flooding cycles in those years compared with 2000 (five cycles in 2000 compared with nine cycles in 2001 and 2002). Compared with CP 95-1429, CP 95-1376 probably needed more exposure to flood to reach similar levels of aerenchyma formation.

It is probable that the greater yield reductions due to periodic flooding in CP 95-1376 compared with CP 95-1429 were due to differences in aerenchyma formation between the two genotypes. In CP 95-1376, lack of constitutive aerenchyma formation may have resulted in ineffective O_2 transport for an unknown time until sufficient aerenchyma formation occurred in response to periodic flooding. Although in 2002, one 7-d flood was sufficient to cause stalk aerenchyma formation in CP 95-1376, it is not known how long it took for this aerenchyma formation to occur after exposure to the flood. Also, the CP 95-1376 exposed to the one flood in 2002 was about 2 mo older than other treatments of CP 95-1376 routinely exposed to flooding. These results suggest that selection for the ability to form constitutive stalk aerenchyma (such as occurred with CP 95-1429) and high yield would be a useful approach for identifying flood tolerance among sugarcane genotypes. It has already been shown that constitutive aerenchyma formation in sugarcane roots is a routine process (Ray et al., 1996; Van Der Heyden et al., 1998).

CONCLUSIONS

For one of two genotypes that was flooded periodically for 1 wk, and then drained to depths of 16, 33, and 50 cm, cane and sugar yields improved in 2 out of 3 yr as depth of drainage increased. Yields of the second genotype, which formed constitutive aerenchyma, were not affected in all 3 yr by depth of drainage after periodic flooding. In the 2 yr in which grubs were not present, differences in genotype response to periodic flooding were consistent. The cane and sugar yields of one of two genotypes were reduced by flooding, and flooding did not affect yields of the genotype with constitutive aerenchyma. If results with these two genotypes are repeated with Florida cultivars, there would be several useful applications. Fields would need to be drained to depths of 50 cm after periodic flooding for cultivars that do not form constitutive aerenchyma. For cultivars with constitutive aerenchyma, drainage depth could be as shallow as 16 cm. When not able to drain all their fields after a flood of extended duration, sugarcane growers could first drain fields of cultivars that do not form constitutive aerenchyma. Based on this research, culti-

Table 7. Ratings of aerenchyma formation in stalks of two sugarcane genotypes exposed to four water table treatments during 2000–2002.

Treatment†	Genotype	2000	2001	2002	Mean
			rating‡		
50 always	CP 95-1376	0.00 B§	0.00 B	0.50 B	0.16 D
50 always	CP 95-1429	0.40 B	0.27 B	0.80 B	0.50 BC
16 and flood	CP 95-1376	0.70 B	1.45 A	2.66 A	1.63 AB
16 and flood	CP 95-1429	2.73 A	1.57 A	2.41 A	2.36 A
33 and flood	CP 95-1376	0.85 B	1.67 A	1.95 A	1.50 AB
33 and flood	CP 95-1429	2.30 A	1.40 A	2.50 A	2.08 A
50 and flood	CP 95-1376	0.60 B	1.43 A	2.00 A	1.34 AB
50 and flood	CP 95-1429	2.99 A	1.57 A	1.87 A	2.12 A
50 always	mean	0.20 B	0.13 B	0.65 B	0.33 B
16 and flood	mean	1.72 A	1.70 A	2.53 A	1.99 A
33 and flood	mean	1.58 A	1.53 A	2.23 A	1.79 A
50 and flood	mean	1.79 A	1.50 A	1.94 A	1.73 A
Mean	CP 95-1376	0.54	1.14	1.78	1.16
Mean	CP 95-1429	2.10	1.29	1.89	1.77
$P > t$		<0.01	0.17	0.22	0.23
Overall mean		1.32	1.22	1.84	1.46

† Target treatments were water table depths of 50 cm always and cycles of flooding for 1 wk followed by depths of 16, 33, and 50 cm for 2 wk for five, nine, and nine cycles in 2000, 2001, and 2002, respectively. After these cycles, target water table depths were 16, 33, and 50 cm.

‡ Highest individual rating of 5 signified about 70% of stalk area was pithy material with aerenchyma.

§ Least square means in the same column and group followed by the same letter are not significantly different at $P = 0.05$ based on t tests.

vars with constitutive aerenchyma should be able to tolerate flood durations of at least 1 wk.

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